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Short-Backfire Antenna with Corrugated Reflector for Radio Astronomical Array Receivers

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Abstract

A short-backfire antenna (SBA) with corrugated structure on the aperture edge of the main reflector is designed to suppress sidelobe and enhance the isolation. The corrugated SBA is suitable for closed-pack antenna array. Early prototype antenna measured results indicate that the radiation pattern is well fit to the design and simulation. The simulation also indicates that the spill over temperature is below 11K over 700- 900MHz if the SBA is integrated to the 100-meter Green Bank Telescope.

1. Introduction

The phased array feed and focal plane array receiver are one of the new trends of the instrumentation for radio astronomy. The idea is to arrange an array of receiver on a large aperture single-dish reflector antenna collect the signal with wider field of view. The detected signal can be also correlated to make beam forming and get higher resolution of the synthesized imaging. To make such array receiver feed antenna is one of the key components. For lower frequency, the space constrains and the limited area of the focal plane make the feed antenna turn to a challenge.

To fulfill the demands of the phased array feed and focal plane array receiver, several types of feed antennas have been developed. For lower frequency, one of the popular antenna types which have been developed almost 50 years back is the short-backfire antenna (SBA). The SBA is composed a dipole pair as excitation source, a big metallic dish as reflector and a smaller metallic dish as the sub-reflector [1]. In the past decade, new types of the SBA have been developed, including the waveguide-fed SBA [2], H-shaped slot fed SBA [3], circular polarized SBA [4], Bowtie-fed SBA [5][6][7], waveguide-fed bow-tie-excited millimeter-wave SBA[8].

In this paper, we designed, fabricated and measured a SBA with a new type of corrugated reflector. The corrugated structure is different to the previously proposed and presented in [9], which is mounted on the upper half of the rim. To make future array feed compact, the effect of the chamfered reflector is also simulated. The measured results are also discussed.

2. Layout of the Antenna

The proposed feed antenna is design for the prime focus feed of the 100-meter Green Bank Telescope (GBT) located in West Virginia for observing the highly red-shift neutral hydrogen emission line among the distant universe around z = 0.5 -1, which corresponded to f = 700 – 900 MHz. The original single-pixel receiver on the telescope is with corrugated waveguide horn antenna as feed, however, the mechanical size and weight is too heave to expanded it into array receiver. The lower band receiver, with operating frequency 380 - 525 MHz, use SBA as feed. Followed the feed antenna, each antenna is equipped with a cryogenically-cooled low-noise receiver for radio astronomy. To minimize the spill over temperature and keep the receiving signal clean enough, the spillover temperature should be kept below 15K, and the main beam should be within the +- 40 degree angle and minimize the sidelobe level outside 39 degree. As the early prototype demonstrated in [10], the feed antenna has to be highly integrated to the receiver cryostat. Part of the receiver cryostat is also served as the tuning elements of the antenna.

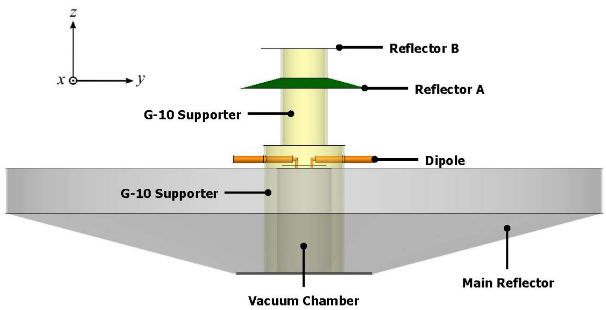
The antenna outline is as shown in Fig. 1. The original one is with only small metallic disk sub-reflector and flat main reflector with rim to guide the radiation pattern from the dipole pair. In [10] we have proposed a revised dipole based SBA with more tuning disks and rings which adapted from [11]. The early prototype SBA is with main reflector (M) with conical disk and rim. In this work, the base radius and flare angle of the main reflector is adjusted, and a corrugation ring facing to the propagating direction is added. Above the dipole pairs, there are two small metallic plate serve as sub-reflectors, including the third reflector (S) on the top, and the conical shape second reflector (C). Near the dipole pair, there are two sleeve plates for impedance tuning, including the upper sleeve plate (U) and the lower sleeve ring (L).

3. Design and Simulation

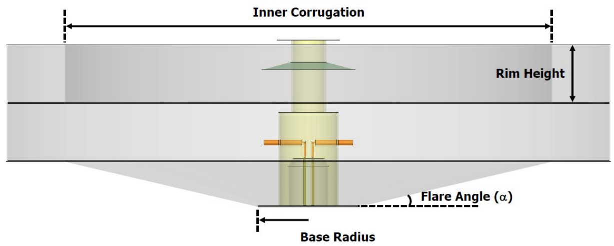
The design of the SBA is aiming to have the following specifications:
(1) 700 – 900 MHz pass bands (wavelength = 333 – 428 mm, centered at 375 mm).
(2) first null of the beam pattern < +- 40 degree
(3) spill over temperature < 13K
(4) coaxial ports reflection coefficient < -8 dB
(5) dimension: with diameter smaller than 1.00 meters

To optimize the performance of the antenna, the parameters to be considered, as shown in Fig. 1 (a), are
(a) radius of the main reflector (R_{R1}, excluding the corrugation structure),
(b) radius of the base plate of the main reflector (R_b)
(c) flare angle of the main reflector conical section (α)
(d) rim height (t_r)
(e) corrugation width (w_c)
(f) corrugation depth (d_c)
(g) radius of the third reflector (R_{R3})
(h) height of the third reflector (h_{R3})
(i) radius of the second reflector (R_{R2})
(j) height of the second reflector (h_{R2})
(k) flare angle of the second reflector (θ)
(l) radius of the upper sleeve diameter (R_{us})
(m) height of the upper sleeve (h_{us})
(n) dipole length (l_d)
(o) dipole height (h_d)
(p) radius of the lower sleeve (R_{ls})
(q) height of the lower sleeve (h_{ls})

The design started from the scaled version of the GBT prime focus receiver for 385 – 520 MHz to the required frequency range, then after fine-tuning the parameters to the initial version, which is with simple reflector with rim. The simulated results of the prototype SBA (Fig. 1(a)) are shown in [11]. However, the half power beam width (HPBW) of the main lobe is too broad at 700MHz edge. Further analysis of the prototype SBA mounting on the prime focus of the GBT indicates that the spill over temperature is too high. The corrugation structure on the surface of the outer rim is proposed to minimize the spill over, as shown in Fig. 1(b). The width and the depth of the corrugation is set to around quarter wavelength, and slightly fine-tuned. The design of the corrugated SBA is then iterated as the different versions described below.



(a)

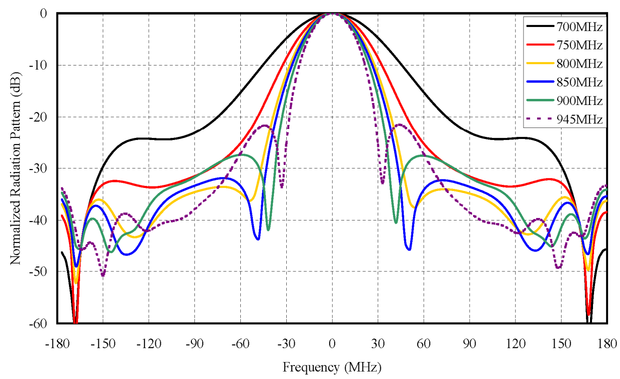


(b)

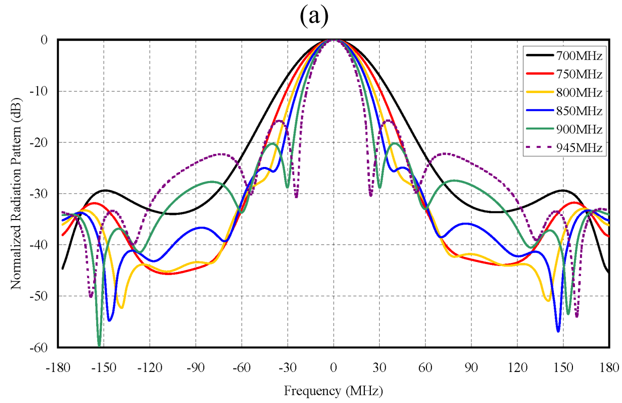
Fig. 1. Mechanical outline of the proposed dipole-fed SBA: (a) early prototype presented in [11], (b) early revised version with corrugation shown in this work.

3.1. Version 1 Corrugated SBA

A quite straightforward approach of the corrugated SBA is adding the corrugated structure to the outer rim of the conical main reflector. The structure of the corrugation is a two-stage version: the top corrugation faced to the wave radiation direction, this corrugation can eliminate the wave scattering outward to the neighboring antenna. The bottom corrugation faced toward the axis of the propagation help to eliminate the back scattering wave from the main reflector. The flare-angle of the conical main reflector is set to 15 degree with 170-mm base plate diameter, which is identical to the prototype shown in [9]. Dimensional details of the version-1 corrugated SBA are shown in Table 1. The simulated radiation pattern is as shown in Fig. 2.



(a)

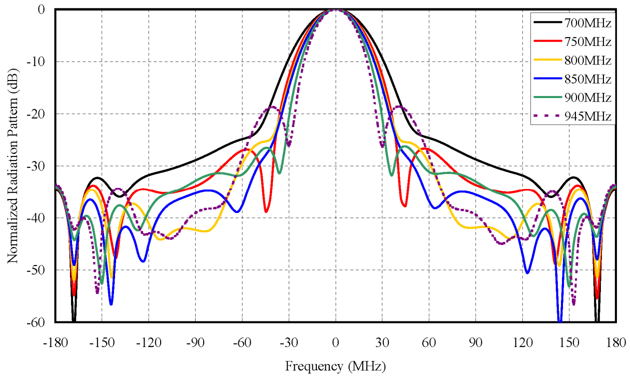


(b)

Fig. 2. Simulated radiation pattern of the version 1 corrugated SBA (a) E-plan pattern, (b) H-plane pattern.

3.2. Version-2 Corrugated SBA

The version-1 corrugated SBA still has high spill over temperature. To minimize the effect, we try to tune the parameters to see if there is any better solution. The flare-angle of the conical main reflector is then trial from 15 degree to 30 degree and the simulated results indicated the spill over temperature can be reduced. Further investigation indicates the flare-angle is optimized at 40 degree to ensure all the top structure is below the corrugation structure of the main reflector. The simulated radiation pattern and the comparison of the simulated spill over temperature is shown in Fig. 3. The optimized dimensions of the antenna are listed in Table I.



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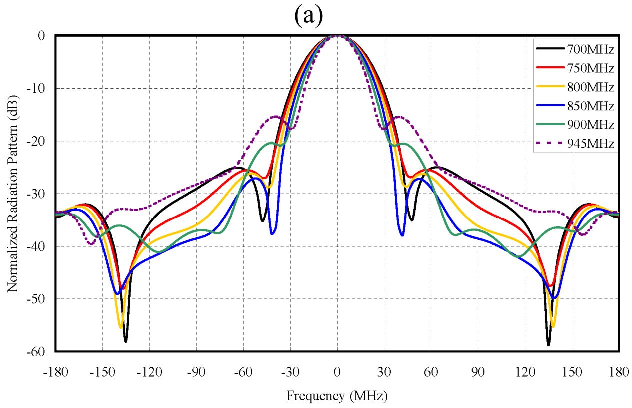

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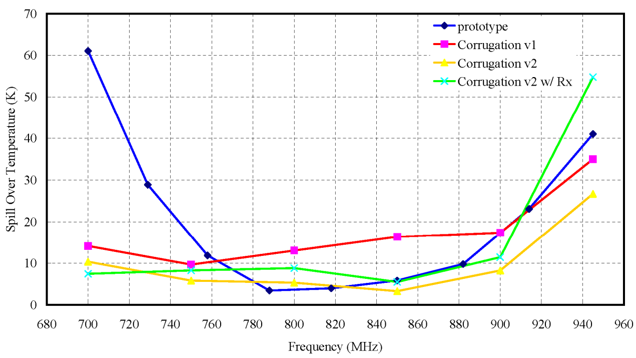


(c)

Fig. 3. Simulated (a) E-plane, (b) H-plane radiation pattern, and (c) spill over temperature of the various short backfire antennas.

Table I. Antenna mechanical size comparison

Parameters	Prototype [11]	corrugated v.1	corrugated v.2
R_{R1}	380mm	415.6mm	375mm
R_b	85	85	285
α	15	15	30
t_r	58	201	202
w_c	N/A	84.4 – 103.5	125 - 142
d_c	N/A	100	102
R_{R3}	55	55	70
h_{R3}	283	284	285
R_{R2}	77.3	77	85
h_{R2}	246	246	246
θ	15	15	15
R_{us}	52.4	52.4	52.4
h_{us}	160.5	160.5	160.5
l_d	244	180	244
h_d	142.6	127.6	127.6
R_{ls}	21.8–27.9 (ring)	30	38.1
h_{ls}	135	106	106

4. Measured Results and Discussion

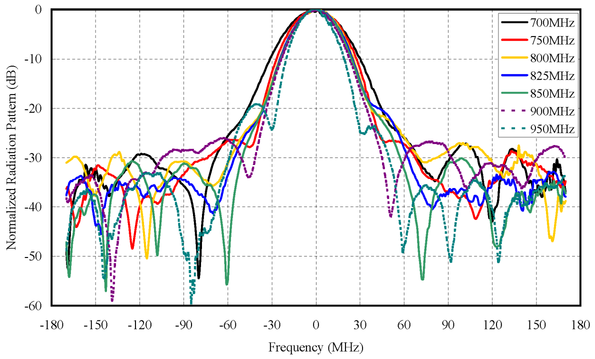
The antenna radiation pattern was measured in two different approaches: (1) conical shape far-field anechoic chamber, (2) outdoor range measurement. The conical shape far-field anechoic chamber is only with operating frequency available from 800MHz, it is used for early verification of the prototype. The corrugated SBA is then measured in the outdoor range facility in Green Bank shown in Fig. 4.

The measured results of the corrugated SBA version 1 and version 2 are shown in Fig. 5. The radiation pattern key parameters are compared in Fig. 6. From Fig. 6(a), one can find that the half-power beam widths are significantly reduced from 54 degree to 33 degree at 700 MHz after revision. From Fig. 6(b), the taper of the power strength at the edge of the 100-meter reflector is improved from -6 dB down to -10 dB at 700 MHz after revision.

(a)

(b)

Fig. 4. Outdoor range measurement facility, (a) overview of the facility: left side is the tower for antenna under test in receiving mode, right side is the tower to install the Yagi-Uda antenna for transmitting signal, (b) the version-2 corrugated SBA under testing mounted on the outdoor near-field range measurement facility.



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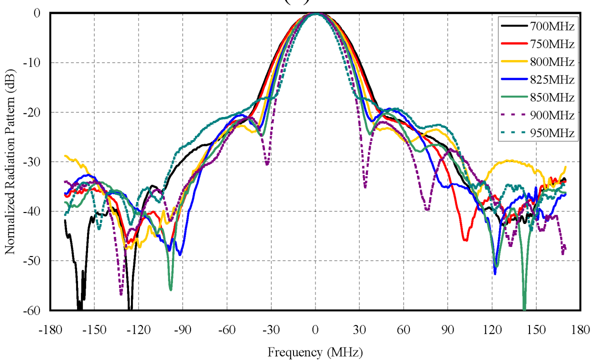
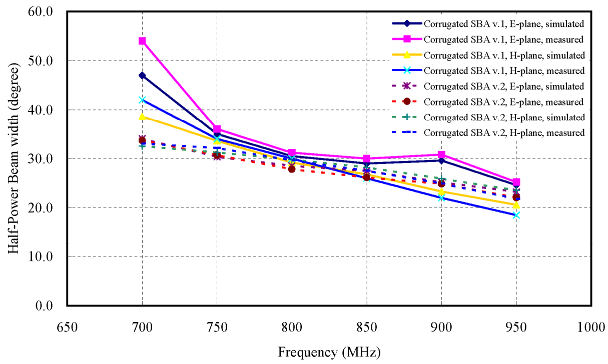
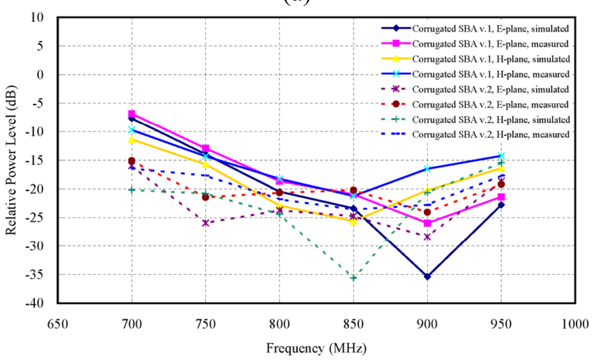


(b)

Fig. 5. Measured E-plane and H-plane radiation pattern of the corrugated SBA: (a) E-plane, version-2, (b) H-plane, version-2.



(a)



(b)

Fig. 6. Comparison of the radiation pattern of the corrugation SBA, (a) half-power beam width (HPBW), (b) taper of the power strength at 39 degree, where corresponding to the angle pointing to the main reflector edge.

6. References

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